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EFFECTS ON SLEEP OF NOISE FROM TWO PROPOSED STOL AIRCRAFT

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Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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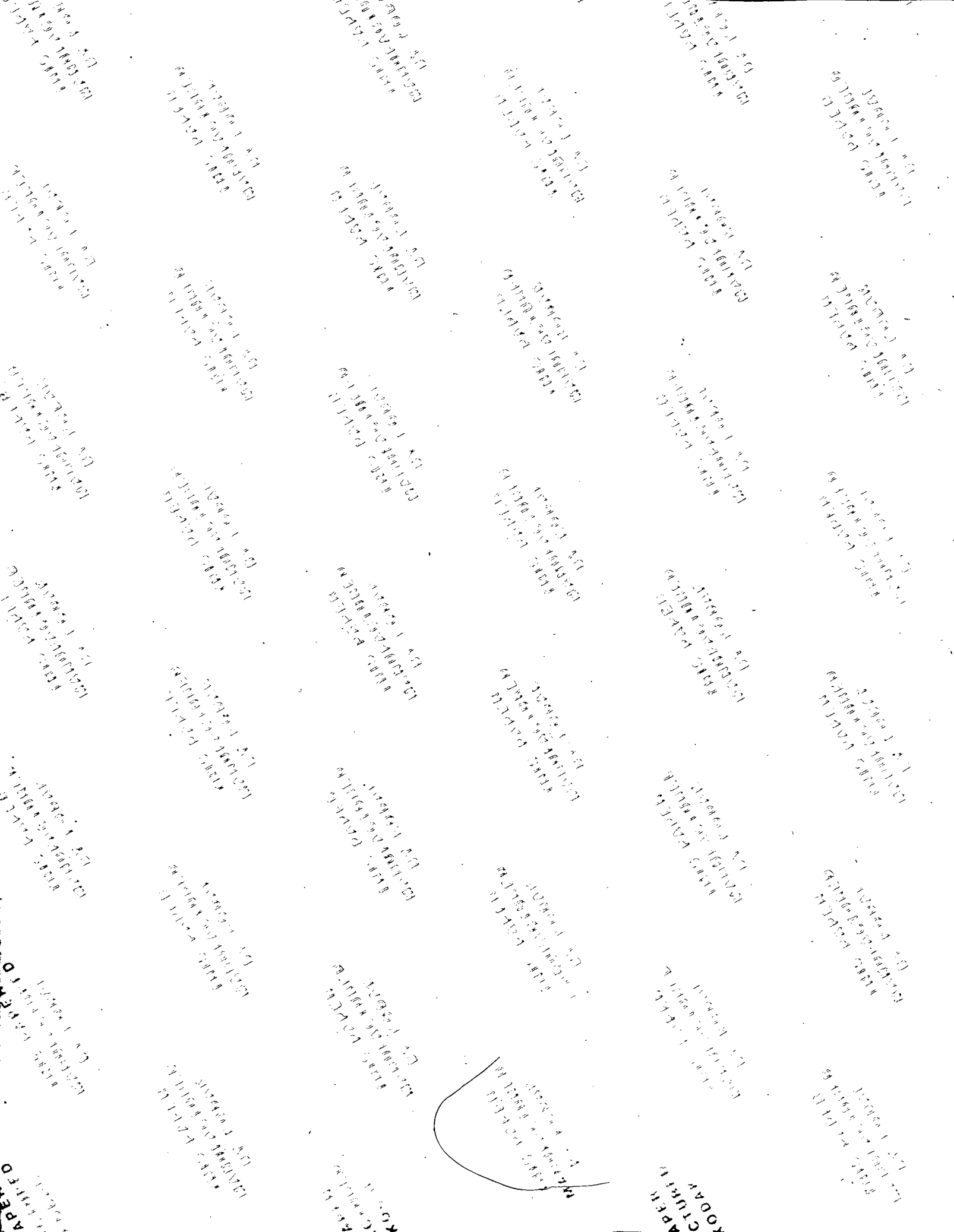
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16. Abstract Responses, both overt behavior and those measured by electroencephalograph, to noise by eight male subjects (36 to 56 years of age) were studied for sixteen consecutive nights. Test stimuli were (1) the simulated sideline noise of a short takeoff and landing (STOL) aircraft with blown flaps, (2) the simulated sideline noise of a STOL aircraft of Turbofan design, (3) the simulated takeoff noise of the blown-flap STOL aircraft, and (4) a four-second burst of simulated pink noise. Responses to each noise were tested at three noise intensities selected to represent levels expected indoors from operational aircraft. Although the protocol called for random presentation of 24 stimuli (four noises, each at three intensities) each night, the vagaries of the subjects' sleeping habits or responses to noise resulted in about 21 stimuli, on the average, being presented during each of the nine test nights. Seven nights were control nights. The results, considered tentative because of the limited number of subjects and trials, indicate that the blown-flap STOL aircraft noise resulted in 8 to 10 percent fewer sleep disturbance responses than did the Turbofan STOL aircraft when noises of comparable intensities from similar maneuvers were used. There was a suggestion of some adaptation to low-intensity stimuli (below about 64 dBA maximum), but the changes observed were not of sufficient magnitude to be statistically significant consistently. Considering the aircraft noises and pink noise bursts used in two studies, the best predictors of the frequency of sleep disturbance were the physical measures of maximum dBA and PNdB. If more diverse types of noises are used, EPNdB appears to be the better predictor of sleep disturbance.					
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EFFECTS ON SLEEP OF NOISE FROM TWO PROPOSED STOL AIRCRAFT

by

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I INTRODUCTION

Short takeoff and landing (STOL) aircraft are being designed and built to ferry passengers from cities to other nearby cities or to very large, transcontinental airports some distance from cities. In order to be accessible to the largest number of people, STOL airports may be located in or near residential areas. Indeed, many older metropolitan airports that may be used are now surrounded by homes or apartments.^{1*}

In designing the aircraft and in planning the locations of the airports, it is important to consider the effects aircraft noise may have on people who are awake or asleep. Whereas techniques for predicting annoyance with aircraft or other noises are reasonably well developed (for example, see Reference 2), only a few first steps toward predicting the effects of noise on sleep³ have been taken. The research reported herein is concerned with noises that simulate two types of STOL aircraft as they might be heard near an airport, but these noises have peak amplitudes at somewhat lower frequencies and are of longer durations than noises used in previous studies.^{3,4,5}

Accordingly, the study had the objectives of (1) providing some information about the comparative effects on sleep of these qualitatively different types of noises, and (2) expanding the database required to develop some general formulation for predicting the effects of any type of noise on human sleep.

* References are listed at the end of this report.

II METHOD

A. Subjects

Eight middle-aged, male volunteers were the subjects in this study. Their ages were 36, 38, 39, 45, 48, 50, 53, and 56 years. All reported themselves to be normal sleepers, not particularly bothered by noise, and without strong bias for or against aircraft noise at night. In Figure 1 the observed hearing loss prior to the study period in the best ear of each subject may be compared to the median expected loss at ages 35 and 55 years;⁶ generally, loss in the worst ear at any particular frequency was, at most, 10 dB greater than in the best ear. That several of the subjects had significant hearing losses is clear. However, it is unlikely that the losses had an appreciable effect on the subjects' ability to hear and respond to the study stimuli because the stimuli were presented at levels well above threshold, and because the noises had peak amplitudes at or below a frequency of about 300 Hz, as determined by one-third octave band analysis, where hearing was near normal. In addition, at frequency bands of 2000 Hz and above (where the hearing losses were very apparent), noise amplitudes, near the subjects' ears, were reduced 12 to 18 dB (for the pink noise burst) and 35 to 45 dB (for the aircraft noises) compared to the peak levels in the 300 Hz and lower bands.

B. Stimuli

Four noises, each at three nominally equivalent dBA levels, were used as stimuli. A list of the noises and some of their physical characteristics as measured at the head position of each bed are presented in Table 1. The spectra of the stimuli displayed as consecutive integrations of 4 s, are shown in Figure 2. It may be noted that the four stimuli uniformly peaked at or below a frequency of 300 Hz. The time courses of the stimuli are illustrated in Figure 3. In Table 1 it should be noted that the measured levels of the Turbofan STOL noise and the pink noise burst were 5 to 6 dB below the level (about 82 dBA) measured midway between the beds. These drops in level were due to unforeseen peculiarities of the loudspeakers and room acoustics. As a consequence, in subsequent sections of this report, comparisons of responses to the different stimuli will be made only when the stimuli are of approximately equivalent (within 1 or 2 dB) intensity in dBA units and nearly equivalent levels are indicated as a single level, for example 82 dBA.

The nominal intensities were selected so as to encompass the levels expected indoors with operational aircraft. Background noise levels in the test rooms were about 35 dBA when the airconditioning was running and about 30 dBA otherwise.

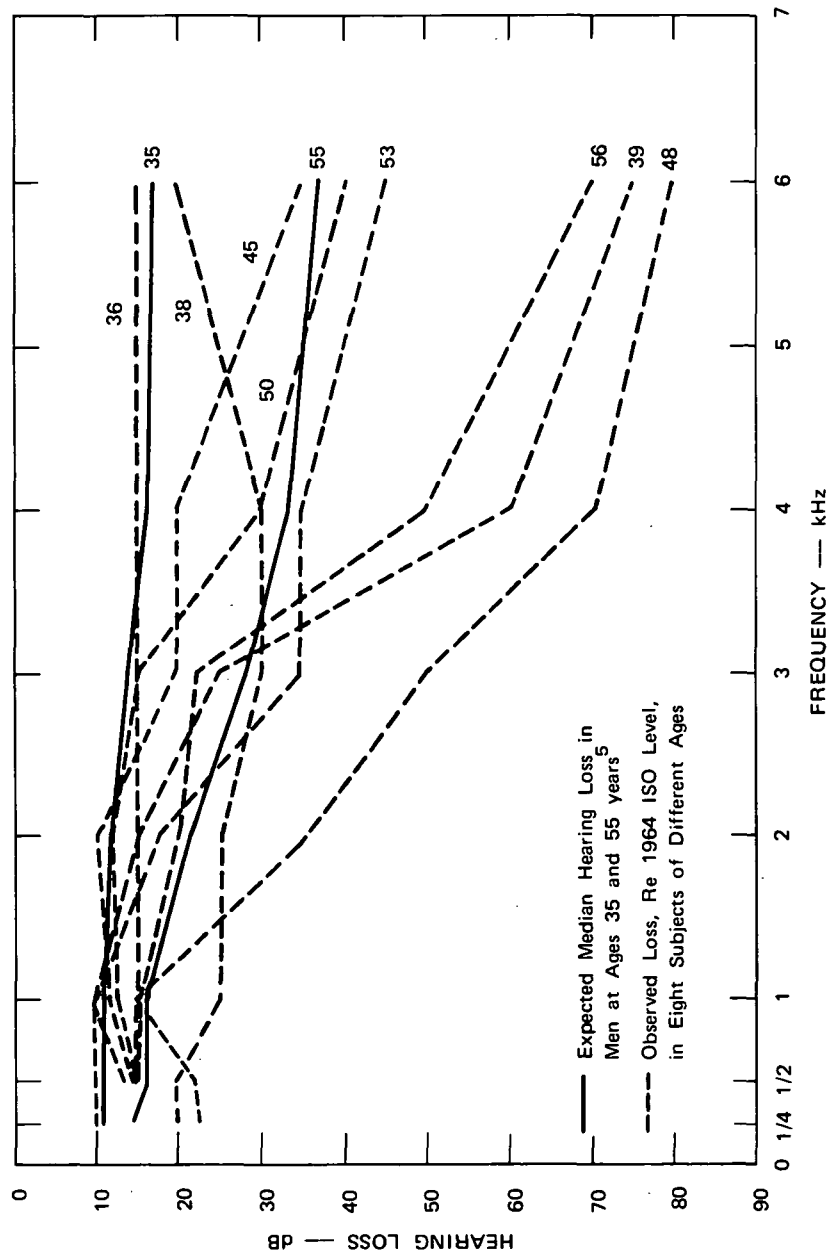


FIGURE 1 HEARING LOSS OBSERVED IN BEST EAR OF EACH OF EIGHT SUBJECTS

Table 1
PHYSICAL DESCRIPTORS OF THE STIMULI

Stimulus	Nominal Overall Duration (seconds)	Nominal Level Between Beds (dBA)	Bed Number	Duration from Maximum dBA to 10 dB Downpoints (seconds)	Measured Level						
					Maximum dBA	Maximum dBC	Maximum PNdB	EdBA*	EdBC†	EPNdB‡	EPNdBT§
Blown-Flap STOL, Sidelane Noise	39	82	1	22	82.9	97.3	95.9	98.2	110.6	110.6	110.6
			2	22	82.1	98.1	95.2	97.6	111.3	110.3	110.5
			3	21	83.7	97.2	95.2	101.0	110.8	110.6	110.7
			4	19	82.4	96.6	94.6	97.0	110.0	109.7	109.9
					82.8**	97.3**	95.3**	98.5**	110.7**	110.3**	110.4**
Blown-Flap STOL, Takeoff Noise	16	82	1	13	80.9	101.5	98.0	99.9	110.1	108.1	108.1
			2	13	80.8	101.8	97.9	100.1	111.8	108.9	108.9
			3	13	81.5	102.3	97.9	100.4	111.1	108.7	108.7
			4	10	80.8	100.7	97.0	99.2	110.2	107.9	107.9
					81.0**	101.6**	97.7**	99.9**	110.8**	108.4**	108.4**
Turbofan STOL, Sidelane Noise††	39	82	1	38	75.6	84.4	86.8	89.7	97.9	102.8	103.2
			2	36	75.7	84.7	86.9	89.0	98.4	102.2	102.4
			3	38	76.1	84.2	87.3	89.5	98.1	102.8	103.1
			4	38	75.6	83.5	86.6	88.9	97.1	102.2	102.6
					75.8**	84.2**	86.9**	89.3**	97.9**	102.5**	102.8**
Pink Noise Burst††	4	82	1	3	76.7	83.1	88.9	89.4	89.1	95.0	95.8
			2	3	76.8	83.7	89.6	90.0	89.6	95.5	95.7
			3	3	77.8	83.8	89.4	89.6	89.9	95.5	95.5
			4	3	76.9	82.7	88.0	88.3	88.7	94.2	94.4
					77.1**	83.3**	89.0**	89.3**	89.3**	95.1**	95.4**

* Effective dBA, integrates levels over the duration between the maximum dBA and the 10 dB downpoints. In this and subsequent columns, 0.5 s is the reference duration. To estimate levels with respect to a reference duration of 8 s, a constant of 12 should be subtracted from all "E" levels.

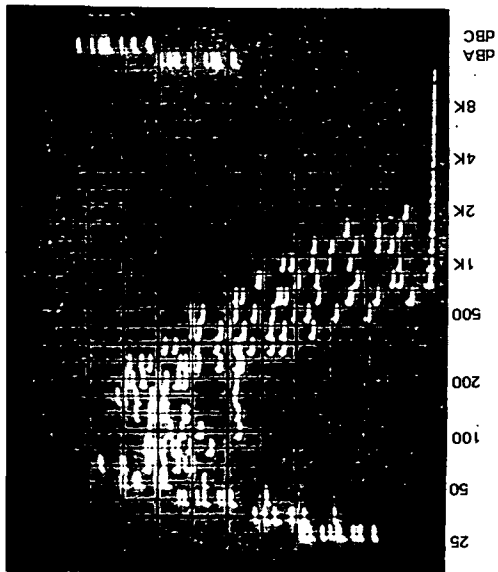
† Effective dBC, integrates levels over the duration between the maximum dBC and the 10 dB downpoints.

‡ Effective PNdB, integrates levels over the duration between the maximum PNdB and the 10 dB downpoints.

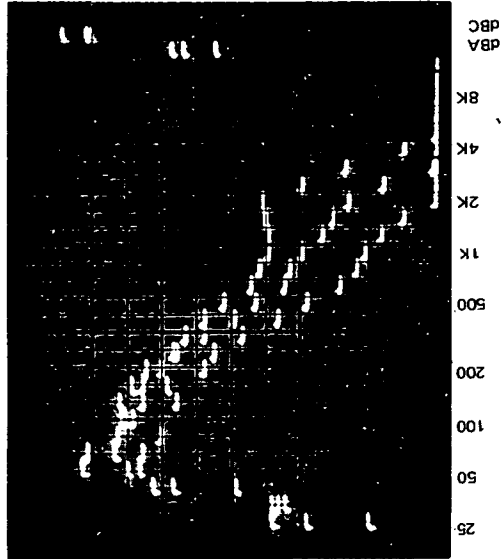
§ Effective PNdB with a correction for pure tone component (see Reference 7) integrated between 10 dB downpoints.

** Mean.

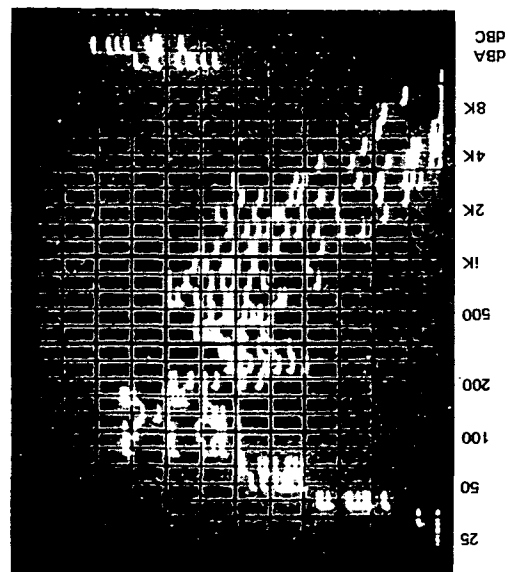
†† Stimulus levels on the magnetic tapes were set to obtain equal dBA levels midway between the beds (and directly below the loudspeakers mounted in the ceilings) in each room. Of course, small and presumably insignificant differences in actual levels were going to be observed at each bed. The low levels (about 6 dB below the 82 dBA observed midway between the beds) found at the four beds for the Turbofan and pink noises can be attributed to peculiarities of the loudspeakers' radiation patterns and room acoustics in these two cases. In contrast, the blown-flap STOL aircraft noises show the expected variation from bed to bed. In subsequent tables and figures the mean levels measured in the beds are used as the stimulus intensity. Levels below the highest level, shown in this table, may be obtained by subtracting the difference between the highest nominal level, 82 dBA, and the two lower nominal levels, 76 and 64 dBA (6 and 18 dB, respectively), from the measured levels shown in the table.



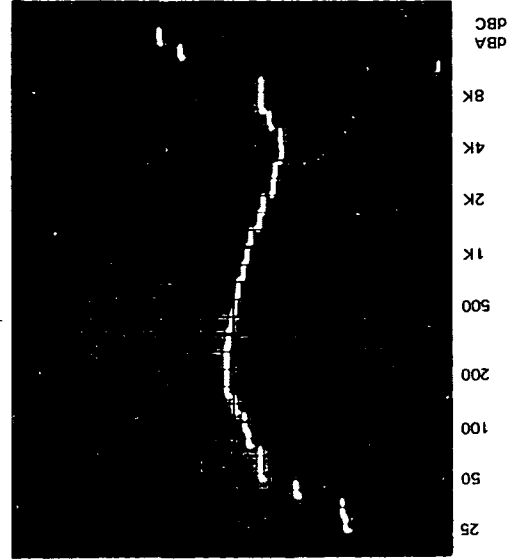
(a) BLOWN-FLAP STOL-SIDELINE



(b) BLOWN-FLAP STOL-TAKEOFF



(c) TURBOFAN STOL-SIDELINE



(d) PINK NOISE BURST

FIGURE 2 ONE-THIRD OCTAVE BAND SPECTRA OF SEQUENTIAL SECTIONS OF THE FOUR NOISES

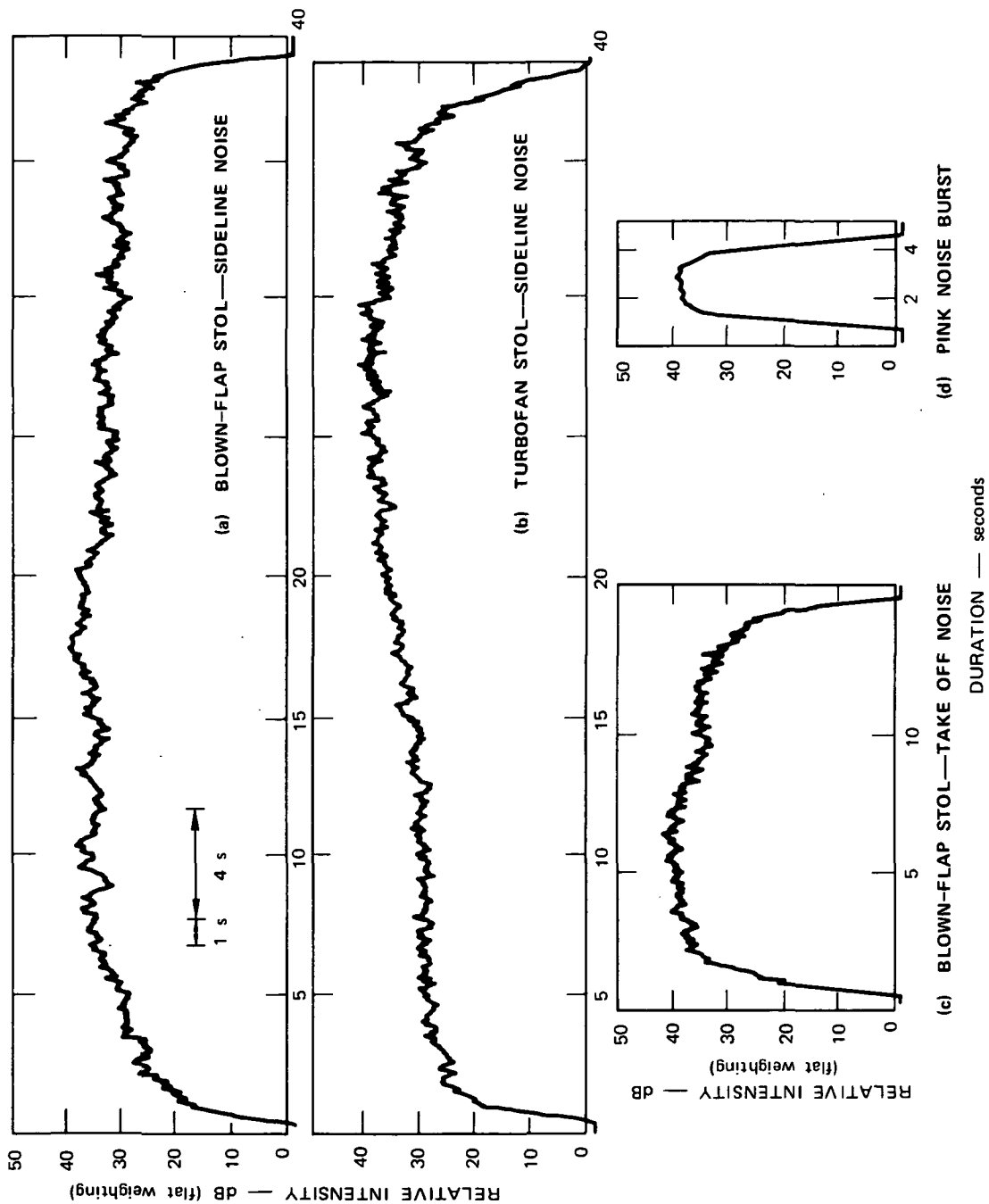


FIGURE 3 TIME HISTORIES OF THE FOUR TEST NOISES

C. Procedure

Each of the subjects slept in the laboratory for 16 consecutive nights. The first four nights were accommodation nights (the data from the first of these four nights was not evaluated); the next six were test nights during which stimuli were presented; there followed two quiet (control) nights, then three test nights, and finally, a control night.

On any test night, the stimuli were presented in random order with respect to both the type of noise and intensity. A different random order was used each night during the first six nights, but the order assigned to the first three nights was repeated on the last three test nights. The process of randomization had the single restriction that each stimulus at each of the three intensities be presented twice nightly. In order to satisfy the restriction, 24 stimulus presentations were planned nightly.

The stimuli were presented at random intervals throughout the night, generally beginning about one-half hour after the subjects retired, but presentation of the first stimulus of the night was delayed until both subjects in any particular room were at least in Sleep Stage 2.⁸ Because, on occasion, one subject took longer to reach Sleep Stage 2 or to return to sleep after being awakened, we were not always able to present the 24 stimuli planned, particularly during the first test nights. On the average, about 21 stimuli were presented each night of the nine test nights.

The subjects were not told when or how many stimuli would be presented. They were instructed to sleep as normally as possible, and to use an "awake switch" affixed to the headboard of each bed within easy reach of the subject if they should awaken for any reason. After the subjects were in bed and the electroencephalogram calibrated and checked for quality, the subjects were asked to press their awake switches as if to assure they were working properly.

On the average, all of the subjects went to bed by 11 p.m. and arose at about 5:30 a.m. Four subjects were tested simultaneously, and frequently the subjects that were first adorned with electrodes went to bed early and fell asleep before the other subjects were ready to retire. On other, infrequent occasions some of the subjects arrived late or awoke early. Generally, however, we were able to obtain about six and one-half hours of sleep electroencephalograms per night on each subject.

D. Scoring the Responses

Monopolar electrodes of Central (C3 or 4) origin referenced to the contralateral mastoid (A1 or A2) were used to obtain the electroencephalogram. In addition, monopolar, horizontal oculograms (referenced to a site just above and between the eyes) and bipolar, lower chin electromyograms were recorded.

The responses to stimulation were scored as they occurred, that is shortly after stimulation, using the criteria listed in Table 2. These scores were later checked independently while the electroencephalograms were being scored for sleep stage percentages; the few inconsistencies found were resolved by mutual agreement between the original scorer and the checker. Sleep stages were scored according to the criteria of Rechtschaffen and Kales.⁸

Table 2
CRITERIA FOR VISUALLY SCORING RESPONSES TO NOISE

Score	Response Required
0	No change in EEG. This category also includes "K complexes," brief bursts of Alpha (about 10 Hz activity), spindles, and eye movements, as appropriate for the subject's sleep stage.*
1	Sleep stage change of one or two steps, but without arousal. The change must occur within 30 seconds of stimulation and continue for at least an additional 40 seconds.
2	Arousal of at least 10 seconds duration, but without use of the "awake" switch. Typically such a record shows brief bursts of Alpha, 10 or more seconds of low-amplitude Beta (20–40 Hz) activity, and gross body movements.
3	Awake response, in which the subject, after arousal, will move about and use the "awake" switch. Usually the response occurs within one minute of stimulus termination.

*"K complexes," Alpha, spindles, and eye movements appear normally in the EEG in some sleep stages. If such activity were scored as a response, the subjects in those stages would appear to be overly sensitive to stimulation as compared to stages in which the activity does not normally occur.

III RESULTS

A. Control Trials

Our laboratory has two test rooms, which permits a stimulus and test procedure in one room while the other room is in a control trial phase. In any given room, test trials typically alternate with control trials throughout the night. The response frequencies observed during the control trials are presented in Table 3, where it may be noted that the frequency of Response Type 0 (no electroencephalographic change) was at least 94 percent during these trials. Trends in spontaneous response frequencies as the study progressed are not apparent. It may be concluded, therefore, that the data presented below are, in the main, responses to the stimuli and not spontaneous or normal changes in patterns of sleep.

Table 3
NUMBERS OF RESPONSES DURING CONTROL TRIALS

Test Nights	Response Type							
	0		1		2		3	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
1,2,3	354	94.1	8	2.1	13	3.5	1	0.2
4,5,6	505	96.9	0	0	15	2.9	1	0.2
7,8,9	449	94.9	4	0.8	19	4.0	1	0.2

B. Response to Stimuli at Different Intensities

Increases of stimulus intensity had two major effects on responses to the four stimuli. With increases of intensity, there was a decrease in the relative frequency of Type 0 responses and an increase in the relative frequency of behavioral awakenings (Type 3 responses). These results are shown in Table 4. It may be noted that there are generally positive changes in percentages of Response Types 1 or 2 with increases of intensity. Pearson coefficients of correlation between stimulus intensity and the frequencies of Response Types 1 and 2 were 0.56 and 0.63, respectively, and both are significantly different from zero at the .05 level of confidence. It is to be expected therefore, that summing the percentages of Response Type 2 (electroencephalographic arousal) and Response Type 3 (behavioral awakening) produced no significant change in the trend, noted earlier, that frequency of behavioral awakening correlated positively with stimulus intensity. This result is consistent with previous results.³

Table 4
NUMBERS OF RESPONSES TO FOUR STIMULI
AT THREE INTENSITIES

(Frequency, in Percent, in Parentheses)

Stimulus	Intensity (Maximum dBA)	Response Type			
		0	1	2	3
Blown-Flap STOL Sideline*	64	72 (67.9)	13 (12.3)	11 (10.4)	10 (9.4)
	76	52 (43.7)	25 (21.0)	19 (16.0)	23 (19.3)
	82	27 (23.1)	34 (29.0)	25 (21.4)	31 (26.5)
Blown-Flap STOL Takeoff†	64	68 (59.6)	17 (14.9)	16 (14.0)	13 (11.4)
	76	43 (38.4)	22 (19.6)	23 (20.5)	24 (21.4)
	82	33 (37.5)	11 (12.5)	15 (17.0)	29 (33.0)
Turbofan STOL Sideline‡	58	76 (69.7)	14 (12.8)	15 (13.8)	4 (3.7)
	70	51 (51.0)	19 (19.0)	16 (16.0)	14 (14.0)
	76	46 (34.1)	38 (28.1)	23 (17.0)	28 (20.7)
Pink Noise Burst§	58	86 (71.1)	14 (11.6)	19 (15.7)	2 (1.7)
	70	55 (48.7)	8 (7.1)	24 (21.2)	26 (23.0)
	76	38 (32.5)	18 (15.4)	22 (18.8)	39 (33.3)

* $\chi^2(1) = 45.66, 6 \text{ df}, p < .001$

‡ $\chi^2 = 35.89, 6 \text{ df}, p < .001$

† $\chi^2 = 21.50, 6 \text{ df}, .01 > p > .001$

§ $\chi^2 = 54.63, 6 \text{ df}, p < .001$

(1) The chi-square statistic assumes that the categories of the dependent variables are mutually exclusive and independent. Our response categories are clearly exclusive but not independent because the subjects were tested repeatedly. However, because each response was scored on its own merits and the response frequencies aggregated over subjects and nights, it would appear that we have approximate independence. The statistic, as used in this and subsequent tables, tests the hypothesis that the observed distributions of response types as a function of stimulus intensity (or other parameters shown in subsequent tables) are identical statistically (or, more formally, the variables are independent).

C. Comparison of Noise from Two Aircraft Types Performing Similar Maneuvers

It was clear in Table 4 that the intensities of the blown-flap and Turbofan STOL aircraft were approximately equivalent at only one test level, 76 dBA. The frequency of responses for these stimuli at 76 dBA are compared in Table 5, where the absence of a statistically significant difference is clear. However, the data presented in Table 4 suggest that, at comparable intensities, the subjects may have been somewhat less disturbed by the sideline noises of the blown-flap STOL than by the Turbofan STOL. The differences in sleep disturbance caused by the two noises are illustrated in Figure 4; it is further suggested by the arrows in Figure 4 that the sideline noise from the blown-flap STOL aircraft might be increased by about 4 dB before it resulted in the degree of disturbance (that is, to 50 percent of the stimuli) caused by the Turbofan sideline noise.

Table 5
NUMBERS OF RESPONSES TO BLOWN-FLAP STOL AND
TURBOFAN STOL SIDELINE NOISES
AT 76 dBA* MAXIMUM INTENSITY
(Frequency, in Percent, in Parentheses)

	Response Type			
	0	1	2	3
Blown-Flap STOL	52 (43.7)	25 (21.0)	19 (16.0)	23 (19.3)
Turbofan STOL	46 (34.1)	38 (28.1)	23 (17.0)	28 (20.7)

* $\chi^2 = 2.93$, 3 df, N.S. (Not Statistically Significant)

D. Responses to Sideline and Takeoff Blown-Flap STOL Aircraft Noise

At the two lower intensities (64 and 76 dBA), no statistically significant differences in response frequencies were observed between the sideline and takeoff noises. See Table 6. As seen in this table with an intensity of 82 dBA, the sideline noise resulted in almost equal frequencies in the four response categories. In contrast, at that intensity, the takeoff noise resulted in a relatively high percentage of Response Types 0 and 3. It may be of some importance to note, however, that at the three intensities tested, the takeoff noise consistently resulted in a higher proportion of behavioral awakenings (or the combination of awakening and arousals — Response Types 3 and 2) than did the sideline noise. These findings suggest that the takeoff noise disrupted sleep more than did the sideline noise despite the fact that the latter noise had a duration almost twice that of the takeoff noise (see Table 1).

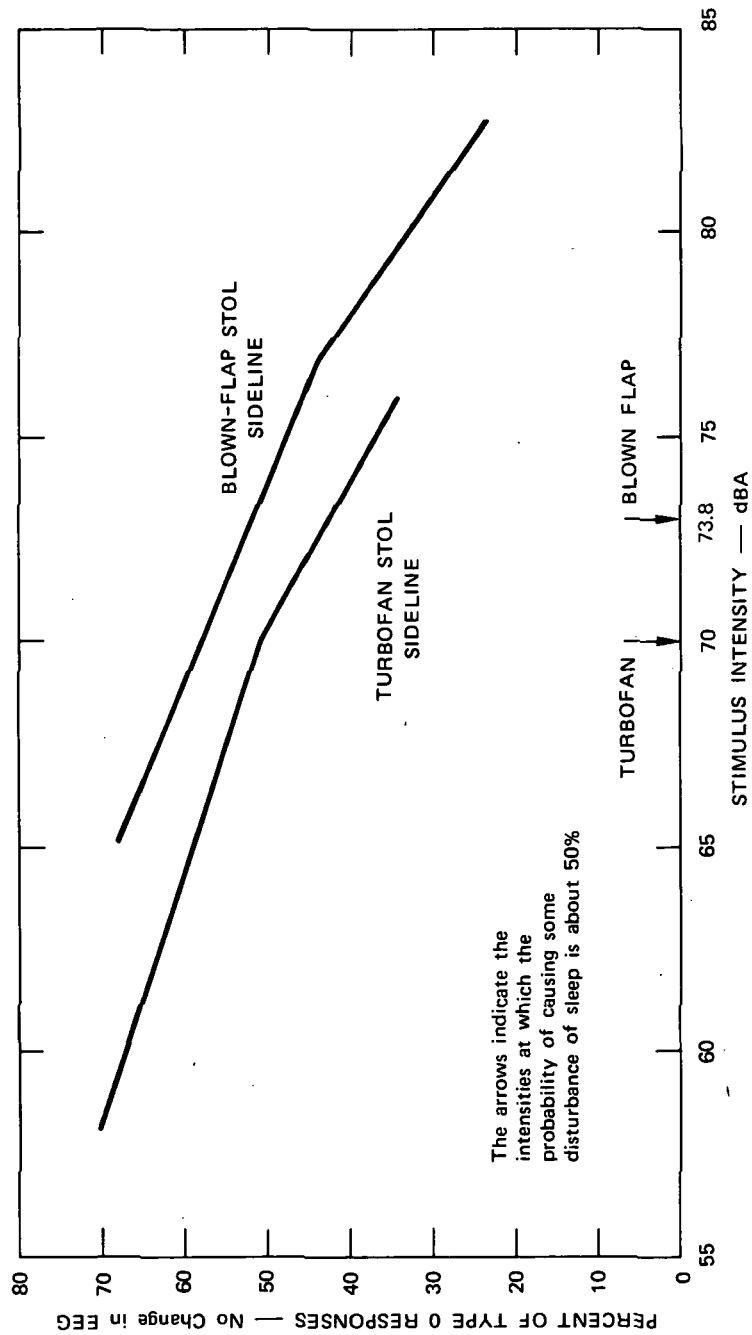


FIGURE 4 RELATIVE DISTURBANCE OF SLEEP BY SIDELINE NOISES FROM TURBOFAN AND BLOWN-FLAP STOL AIRCRAFT

Table 6

**NUMBERS OF RESPONSES TO SIDELINE AND TAKEOFF
BLOWN-FLAP STOL AIRCRAFT NOISES**

(Frequency Percentage in Parentheses)

Intensity (Maximum dBA)	Blown-Flap Noise	Response Type			
		0	1	2	3
64*	Sideline	72 (67.9)	13 (12.3)	11 (10.4)	10 (9.4)
	Takeoff	68 (59.6)	17 (14.9)	16 (14.0)	13 (11.4)
76†	Sideline	52 (43.7)	25 (21.0)	19 (16.0)	23 (19.3)
	Takeoff	43 (38.4)	22 (19.6)	23 (20.5)	24 (21.4)
82‡	Sideline	27 (23.1)	34 (29.0)	25 (21.4)	31 (26.5)
	Takeoff	33 (37.5)	11 (12.5)	15 (17.0)	29 (33.0)

* $\chi^2 = 1.68$, 3 df, N.S.

† $\chi^2 = 1.48$, 3 df, N.S.

‡ $\chi^2 = 11.04$, 3 df, $.02 > p > .01$

E. Adaptation

In general, there appeared to be little adaptation (defined in terms of an increasing percentage of Type 0 responses and a simultaneous decreasing percentage of Type 3 responses with continuing nights of stimulation) when the nine test nights are considered. In Table 7, the results of test nights 1, 2, and 3, those of 4, 5, and 6, and those of 7, 8, and 9 are combined to obtain more accurate estimates of response frequencies during those nights. For a given stimulus at a given intensity it does appear that the trend of the data, in general, is toward a decreasing frequency of behavioral awakenings (Response Type 3) and an increasing frequency of Type 0 responses during nights 4, 5, and 6 as compared with nights 1, 2, and 3. For example, with the 82 dBA blown-flap sideline noise on the first three nights the subjects were awakened by 27.3 percent of the stimulus presentations and showed no response (Type 0) to 21.2 percent of them. In contrast, on nights 4, 5, and 6,

Table 7

**NUMBERS OF RESPONSES TO THE STIMULI AT THE VARIOUS INTENSITIES
FOR TEST-NIGHT COMBINATIONS**

(Frequency in Percent in Parentheses)

Intensity (Maximum dBA)	Test Nights	Response Type				χ^2 , @ 6 df	Significance Level
		0	1	2	3		
(a) Blown-Flap STOL Aircraft Sideline Noise							
64	1,2,3	13 (46.4)	3 (10.7)	5 (17.9)	7 (25.0)	15.06	.02 > p > .01
	4,5,6	32 (76.2)	5 (11.9)	4 (9.5)	1 (2.4)		
	7,8,9	27 (75.0)	5 (13.9)	2 (5.5)	2 (5.5)		
76	1,2,3	11 (45.8)	3 (12.5)	6 (25.0)	4 (16.7)	6.73	N.S.
	4,5,6	24 (47.1)	8 (15.7)	7 (13.7)	12 (23.5)		
	7,8,9	17 (38.6)	14 (31.8)	6 (13.6)	7 (15.9)		
82	1,2,3	7 (21.2)	10 (30.3)	7 (21.2)	9 (27.3)	3.36	N.S.
	4,5,6	13 (29.5)	14 (31.8)	8 (18.2)	9 (20.5)		
	7,8,9	7 (17.5)	10 (25.0)	10 (25.0)	13 (32.5)		
(b) Blown-Flap STOL Aircraft Takeoff Noise							
64	1,2,3	17 (50.0)	7 (20.6)	5 (14.7)	5 (14.7)	6.67	N.S.
	4,5,6	27 (72.9)	4 (10.8)	3 (8.1)	3 (8.1)		
	7,8,9	24 (55.8)	6 (13.9)	8 (18.6)	5 (11.6)		
76	1,2,3	12 (50.0)	2 (8.3)	4 (16.7)	6 (25.0)	5.85	N.S.
	4,5,6	19 (39.6)	12 (25.0)	10 (20.8)	7 (14.6)		
	7,8,9	12 (30.0)	8 (20.0)	9 (22.5)	11 (27.5)		
82	1,2,3	8 (40.0)	2 (10.0)	3 (15.0)	7 (35.0)	5.86	N.S.
	4,5,6	13 (40.6)	1 (3.1)	6 (18.8)	12 (37.5)		
	7,8,9	12 (33.3)	8 (22.2)	6 (16.7)	10 (27.8)		

Table 7 (cont.)

Intensity (Maximum dBA)	Test Nights	Response Type				χ^2 , @ 6 df	Significance Level
		0	1	2	3		
(c) Turbofan STOL Aircraft Sideline Noise							
58	1,2,3	24 (68.6)	5 (14.3)	3 (8.6)	3 (8.6)	5.86	N.S.
	4,5,6	25 (65.8)	6 (15.8)	6 (15.8)	1 (2.6)		
	7,8,9	27 (75.0)	3 (8.3)	6 (16.7)	0 (0)		
70	1,2,3	9 (39.1)	6 (26.1)	5 (21.7)	3 (13.0)	4.00	N.S.
	4,5,6	22 (50.0)	7 (15.9)	7 (15.9)	8 (18.2)		
	7,8,9	20 (60.6)	6 (18.2)	4 (12.1)	3 (9.1)		
76	1,2,3	13 (30.2)	15 (34.9)	6 (14.0)	9 (20.9)	2.15	N.S.
	4,5,6	17 (35.4)	12 (25.0)	10 (20.8)	9 (18.8)		
	7,8,9	16 (36.4)	11 (25.0)	7 (15.9)	10 (22.7)		
(d) Pink Noise Burst							
58	1,2,3	18 (51.4)	7 (20.0)	8 (22.9)	2* (5.7)	12.85	.05>p>.02
	4,5,6	38 (82.6)	3 (6.5)	5 (10.9)	0* (0)		
	7,8,9	30 (75.0)	4 (10.0)	6 (15.0)	0* (0)		
70	1,2,3	10 (37.0)	5 (18.5)	4 (14.8)	8 (29.6)	9.60	N.S.
	4,5,6	25 (49.0)	2 (3.9)	12 (23.5)	12 (23.5)		
	7,8,9	20 (57.1)	1 (2.9)	8 (22.9)	6 (17.1)		
76	1,2,3	6 (25.0)	1 (4.2)	3 (12.5)	14 (58.3)	11.73	N.S.
	4,5,6	15 (31.3)	7 (14.6)	12 (25.0)	14 (29.2)		
	7,8,9	17 (37.8)	10 (22.2)	7 (15.6)	11 (24.4)		

*Expected frequencies are below 1, and, therefore, Response Types 2 and 3 are combined for the calculation; but 6 df is used to assess the significance. To check the result, χ^2 also was computed without the combination; there was no change in significance level.

the subjects were awakened by only 20.5 percent of the presentations and showed an increased frequency of Type 0 responses to 29.5 percent. But the two nights of uninterrupted (noise-free) sleep interposed between test nights 6 and 7 appear to have negated any adaptation to the stimuli that may have occurred during the first six nights with noise. Thus, with the blown-flap takeoff noise at 82 dBA, the subjects showed an increased frequency (to 32.5 percent) of awakenings as compared to the 20.5 percent observed on nights 4, 5, and 6, and a decrease in frequency of Type 0 responses (to 17.5 percent) as compared to 29.5 percent Type 0 responses observed on nights 4 to 6. Note also that in several instances (with the blown-flap STOL aircraft sideline and takeoff noises at 76 and 82 dBA, respectively, or with the Turbofan noise at 70 dBA), the percentage of behavioral awakenings was higher on nights 4, 5, and 6 than it was on nights 1, 2, and 3, and in these cases, the two nights of quiet sleep resulted in a reduced percentage of behavioral awakenings compared to the frequency on nights 4, 5, and 6. In these cases, changes in the percentage of Type 0 responses did not show any consistent trend.

In most of the other cases, there was a reduction in the frequency of behavioral awakenings and an increase in the frequency of occurrences of no EEG change when comparing *only* nights 4, 5, and 6 with nights 1, 2, and 3. However, these changes were not of sufficient enough magnitude to obtain statistical significance. Perhaps it is worthwhile to note that the two statistically significant differences in response frequencies were observed only for the lowest stimulus intensities tested, and that the other two low-intensity conditions (blown-flap STOL takeoff at 64 dBA and Turbofan sideline at 58 dBA) show rather sizeable reductions (during the first six nights, at least) in awakenings and increases in frequency of Type 0 responses. These results suggest that some adaptation to low-intensity noises may occur; however, the sample sizes in this study seemingly are too small to demonstrate a statistically significant effect.

Another, possibly meaningful, way of defining adaptation is in terms of the time the subject remains "awake" after behavioral awakening or arousal. Because the subjects, after awakening or arousal, returned to Sleep Stage 1 rapidly (as may be inferred from data presented below), the time between use of the awake switch or the end of the arousal period and the beginning of the next Sleep Stage 2 was determined. The results, presented in Table 8, appear to follow one trend shown in Table 7, that is, the adaptation that occurred during the first six nights of tests was apparently lost following two nights of sleep in the quiet. With respect to the mean times to Sleep Stage 2 after awakening or arousal, however, the changes observed were small (slightly over a minute between nights 1, 2, and 3 and nights 4, 5, and 6 in the case of behavioral awakening), so it is unlikely that the subjects perceived any difference. The fact that the standard deviation became smaller as the test nights progressed indicates that in the later test sessions there were fewer instances in which the subjects stayed awake long after being awakened or aroused.

Table 8

TIME REQUIRED TO RETURN TO SLEEP STAGE 2

Preceding Response Type	Test Nights	Mean (minutes)	Standard Deviation
Behavioral awakening, Type 3	1,2,3	4.7	3.4
	4,5,6	3.4	2.4
	7,8,9	3.8	1.5
Arousal, Type 2	1,2,3	2.07	1.85
	4,5,6	1.75	1.42
	7,8,9	1.80	1.27

Generally, the subject, after an arousal, returned to Sleep Stage 2 in about half the time required to return to the same stage after behavioral awakening.

F. Effects of Noise on Sleep Patterns

On control nights, the eight subjects of this study did not show a sleep stage percentage pattern greatly different from that reported by Webb,⁹ as is illustrated in Figure 5. Webb's original subjects were divided into age groups of 30 to 39 years and 50 to 59 years. Because the average age of our subjects is about 46 years, it was thought that an average of Webb's two age groups would be a more reasonable estimate of the expected stage percentages for our subjects. His data were treated accordingly.

With respect to changes in pattern as a result of the noises, in Figure 5 it may be seen that on test nights small increases in Sleep Stages 0, 1, 2 and arousal and movement time were observed as well as decreases in Stages Delta (3 and 4) and REM. These changes are in expected directions,¹⁰ but they are of small magnitude. Only the two percentage point decrease between control and test nights observed in Sleep Stage REM was found to be statistically significant at the 0.05 level.

In passing, it should be noted that this study's lack of large shifts in sleep stage percentages are generally consistent with changes of the same magnitude reported by Collins and Iampietro¹¹ to simulated sonic booms, those reported by Johnson et al¹² in response to "pings", and as reported by several other studies (see the Proceedings cited in Reference 3).

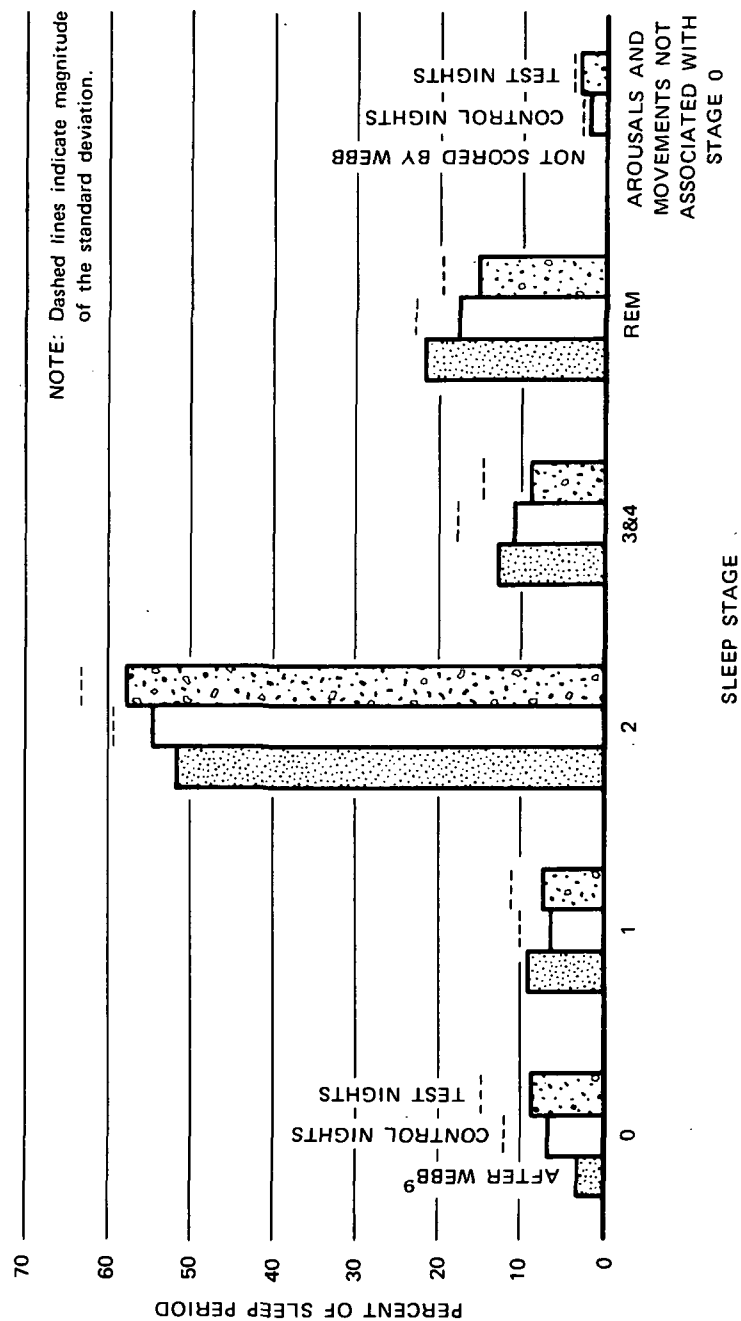


FIGURE 5 SLEEP STAGE PERCENTAGES REPORTED BY WEBB⁹ AND OBSERVED IN THIS STUDY

G. Correlations Between Physical Measures of Noise and Sleep Disturbance

Using results from several laboratories in which different types of noises were stimuli, an earlier study³ suggested that a measure of noise incorporating both spectral and durational information – such as EPNdB – predicted disturbance of sleep better than did other physical measures. In order to verify that result, we present Pearson coefficients of correlation between various physical measures of noise and sleep disturbance data from this study and from a previous study in Table 9. The table includes data from this study only and data from this study in combination with a previous study. Two coefficients, dBC and EdBC, (they are the coefficients of lowest magnitude in the upper section), appeared unpromising and were excluded from the composite results.

Table 9
COEFFICIENTS OF CORRELATION BETWEEN PHYSICAL MEASURES OF
NOISE INTENSITY AND TYPES OF RESPONSES

Response Type	Physical Measure							
	Maximum dBA	Maximum dBC	Maximum PNdB	Peak PNdB	EdBA	EdBC	EPNdB	EPNdBT
0*	-.954	-.788	-.914	-.898	-.902	-.742	-.848	-.845
3*	.915	.773	.909	.870	.790	.662	.747	.747
0 [†]	-.947		-.906	-.882	-.885		-.808	-.813

* Results are from this study only; 12 data points.

[†] Results are from this study and a previous study.¹³ Stimuli were a burst of pink noise and aircraft noises from jet aircraft with and without acoustically-treated engine nacelles; 18 data points in all.

Consistent with our earlier study, these data suggest that the physical measures of noise uniformly predict the frequency of Response Type 0 (no change in the EEG) better than they do the frequency of behavioral awakening (Response Type 3). With respect to the relative accuracy of the different physical measures of noise intensity, those measures not accounting for durational differences, maximum dBA and PNdB, were somewhat more accurate predictors than EdBA or EPNdB, which account for duration. The effect was apparent if the database included the results of the present study or of this study and the earlier one, and in both cases the dBA measures appear to be slightly more effective than PNdB.

It must be remembered that the various physical measures are highly intercorrelated because they are computed from the same basic one-third octave band data and because the computational formulae are similar. For example, the correlation coefficients between the various physical measures shown in Table 1 range between about 0.67 and 0.97. If we assume the average intercorrelation between the various physical measures to be about 0.80, and the average correlation between the measures and the percentage of responses to be about 0.90, then a difference of about 0.10 correlation units between two coefficients is required to be statistically significant at the 0.05 level of confidence. On the other hand, if the average intercorrelation is about 0.40, a difference of about 0.2 units is required to attain the same level of significance. In other words, because of the high intercorrelations between the various physical measures, only small differences in magnitudes of the correlations between the physical measures and the response frequencies are required to obtain statistically significant differences. Because of the small number of noises studied, there is little reason for a detailed analysis of the coefficients; rather, they are presented here to indicate the relative predictive stability as the number of types of noises is increased. Figures 6 and 7 permit comparison of the distribution the no EEG response data points used to compute the coefficients with the maximum dBA and maximum PNdB measures of intensity. As would be expected from the magnitude of the coefficients, the data points with maximum PNdB (Figure 7) generally show somewhat greater dispersion from the regression line than do the points with maximum dBA (Figure 6), but the points in both figures consistently decrease as intensity increases.

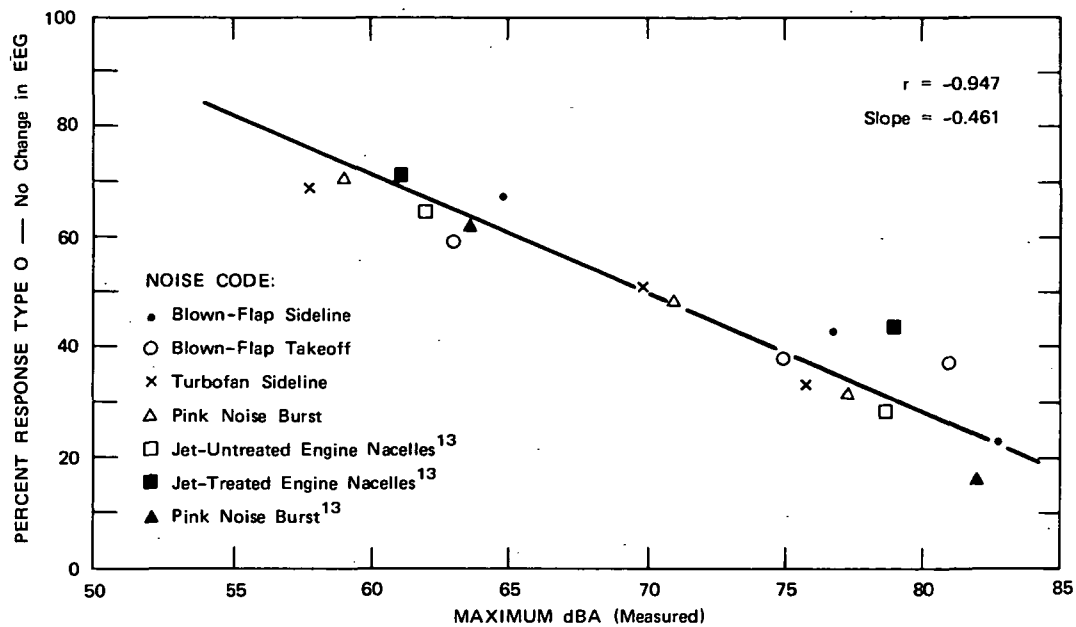


FIGURE 6 DATA POINTS* SHOWING FREQUENCY OF NO DISRUPTION OF EEG PATTERN IF DIFFERENT NOISES ARE MEASURED IN UNITS OF MAXIMUM dBA

* From the present study and that of Lukas et al.¹³

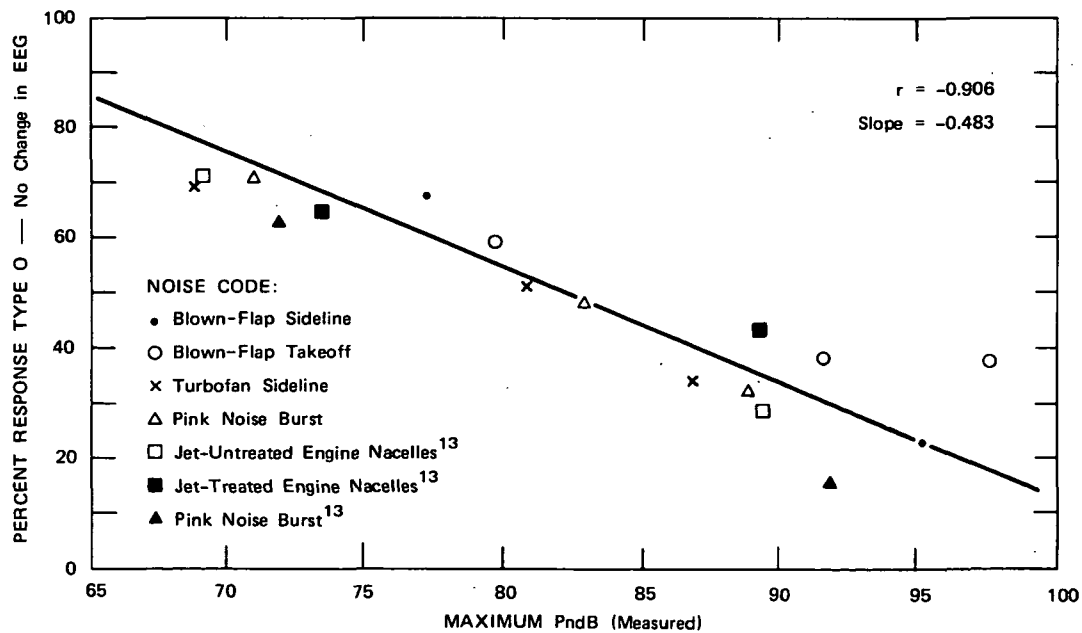


FIGURE 7 FREQUENCY* OF NO DISRUPTION OF EEG PATTERN IF DIFFERENT NOISES ARE MEASURED IN UNITS OF MAXIMUM PndB

* From the present study and that of Lukas et al.¹³

IV DISCUSSION

In either Figure 6 or 7, the data points associated with any of the six types of noises do not appear to be consistently above or below the regression lines. This finding suggests that the percentage of Response Type 0 found in two studies reflects random variations about some mean probability of sleep disturbance (a change of at least one sleep stage or any response other than Type 0) by noises of varying intensities and, possibly, regardless of source. It may be useful to suggest tentatively, therefore, that when similar noises at different intensities occur throughout the night, the intensity at which about 50 percent of the population (of similar age and sex as studied here) will show a change of at least one stage of sleep is approximately 70 dBA maximum. Further, the "threshold" intensity, at which only a small percentage (perhaps 5 percent or less) of a population similar to that tested will show significant disruption of sleep, appears to be approximately 47 dBA.

A possibly more important implication of this analysis is that the physical measures found useful in predicting annoyance with noise in the awake individual, may be useful in predicting disturbance of sleep. Of course, tests with a more diverse group of test noises and large numbers of subjects are required to establish which measure may be the best predictor. An earlier paper³ reported such an effort. Data from several laboratories that tested a variety of noises with both sexes and several age groups were used to calculate the coefficients. The results indicated that the EPNdB measure was better than maximum dBA (the coefficients were -0.78 and -0.62, respectively) in predicting percentage of Response Type 0. That result apparently is at variance with the result of the study reported herein. It must be noted, however, that in the earlier study the results obtained, when only a small number of data points were used, did coincide with the present results; that is, maximum dBA and PNdB predicted the frequency of no sleep disturbance better than did EPNdB. But, after the results from the other laboratories were included into the database, EPNdB predicted the frequency of no sleep disturbance better than did maximum dBA. The apparent inconsistency of results obtained with a small number (or variety) of noise with those obtained when a broad group of noise types are tested clearly indicates the need for additional correlational studies.

V CONCLUSIONS

Because of the limited numbers of subjects tested and STOL aircraft noises used, the conclusions must be considered tentative.

- While performing similar maneuvers, STOL aircraft with blown flaps appear to cause less disruption of sleep than do Turbofan STOL aircraft. At comparable intensities (measured in units of maximum dBA), noise from STOL aircraft with blown flaps appear to result in 8 to 10 percent less sleep disturbance than noise from Turbofan aircraft.
- There is some suggestion of adaptation to stimuli of low intensity (below about 64 dBA); however, the percentages obtained were not consistently of statistically significant magnitudes for each of the four test noises.
- For the aircraft noises and the pink noise bursts tested in this study, it appeared that maximum dBA and maximum PNdB are relatively better predictors of the frequency of some sleep disturbance (a change in sleep stage, arousal, or behavioral awakening) than are EdBA or EPNdB. This result, which was consistent with an earlier study also of a limited number of other aircraft noises, may not occur when using a variety of noise sources under a wide range of intensities.³

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